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Phase-resolved spectra of the millisecond pulsar SAX J1808.4–3658

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Abstract. We analyze the *RXTE* observations of the April 1998 outburst of SAX J1808.4–3658. We show that the soft blackbody component of the X-ray spectrum is from the hotspot on the neutron star surface, while the hard component is from Comptonization of these blackbody photons in the plasma heated by the accretion shock. The disc cannot provide enough seed photons for Comptonization. It is truncated into an optically thin flow at $\sim$ 20–40 R_g by some generic mechanisms common for black holes and neutron stars. Only below the truncation radius the flow is disrupted by the magnetic field and collimated onto the surface. The pulse profiles of both spectral components imply several constraints on the geometry of the system: the inclination angle, location and size of the hotspot and the shock.

The X-ray spectrum of the millisecond pulsar can be fitted by a two-component model consisting of a soft blackbody and a hard Comptonization, with weak Compton reflection. We attribute the soft component to the hotspot on the neutron star and the hard component to a plasma heated in the accretion shock as the material collimated by the magnetic field impacts onto the surface. The soft and hard fluxes are tightly correlated, so probably the hotspot is due to reprocessing of the kinetic energy of the accretion flow and hard X-ray irradiation. The geometry advocated here (see Figure 1) implies that the hotspot is the dominant source of seed photons for Comptonization in the shock, while the seed photons from the disc or self-absorbed synchrotron are negligible.

In the phase-resolved spectra the two components pulse independently, retaining their spectral shape as a function of spin phase. The constancy of the hard X-ray spectral shape implies that the hard X-rays are from a single emission region, rather than being the sum of a spatially separated pulsed and unpulsed components. The large amplitude of variability of the hotspot (see Figure 2*a*) implies large inclination of the system, $\sim 60°$, *if* the angle between spin and magnetic axes is small ($\sim 10°$). Lack of secondary maxima in both profiles implies that we do not see the second magnetic pole – neither the hotspot nor the shock. This, in turn, constrains the shock height to be less than $\sim 10\%$ of the neutron star radius. The pulse profiles of the soft and hard components and are shifted in phase by about 50° (Figure 2). The soft blackbody component is optically thick, so its variability is dominated by its changing projected area, while

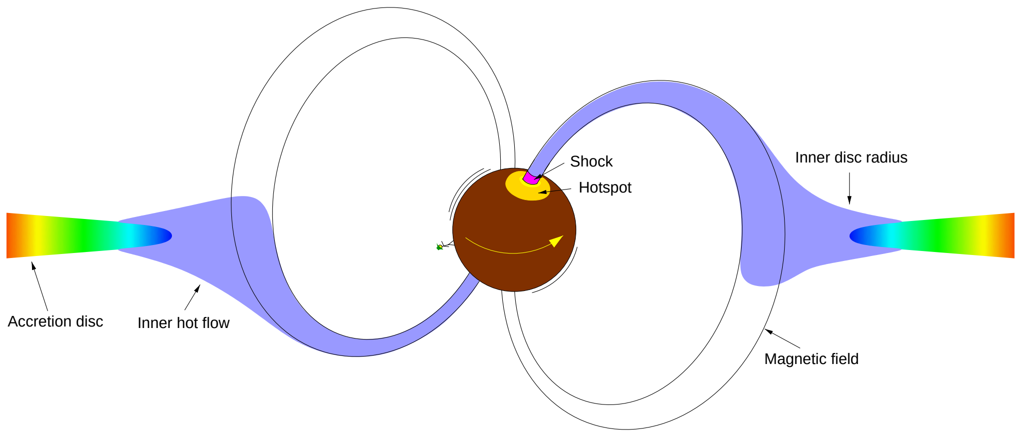

Figure 1. Geometry of SAX J1808.4–3658.

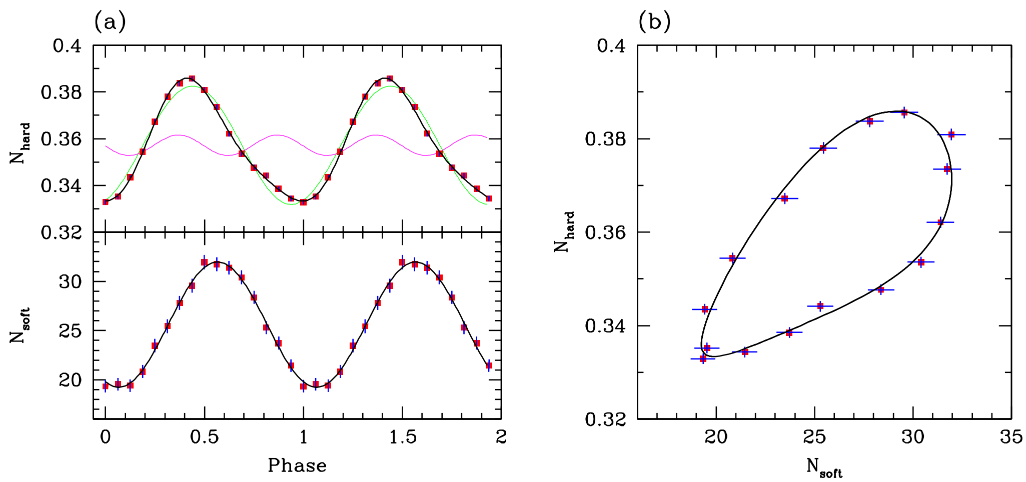

Figure 2. Pulse profiles of the soft and hard spectral components. $N_{\rm soft}$ and $N_{\rm hard}$ are the soft and hard component normalizations.

the Doppler shifts (which are maximised 90° before the maximum in projected area) are somewhat stronger for the translucent accreting shock. This phase shift will manifest itself as the observed energy-dependent time lag in which soft photons lags hard ones. A skewness of the hard component pulse profile (Figure 2*a*) can be a sign of an elongated cross-section of the shock.

The inner disc radius, ∼20–40 R_g, derived from the amount of reflection is consistent with that derived from the relativistic disc models for the origin of the QPO and break in the power density spectra. The evolution of the inner radius is *not* consistent with the magnetic field truncating the disc. Instead it seems more likely that the inner disc radius is set by some much longer time-scale process connected to the overall evolution of the accretion disc. This disc truncation mechanism would then have to be generic in all low mass accretion rate flows both in disc accreting neutron stars and black hole systems.